

Dichotic Word Recognition for Young Adults with Normal Hearing

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## **ABSTRACT**

Dichotic word recognition was measured in young adults with normal hearing at six intensity levels to produce a performance-intensity function. The 50%-correct threshold and slope of the function were compared to that of performance-intensity functions of monaural listening tasks. Differences in right and left ear performance were also compared to explore possible ear advantage effects. The resultant performance-intensity function displayed the characteristic s-shape of monaural listening tasks, but had a higher 50%-correct threshold and a shallower slope. Both of these observations can be attributed to the difficulty of dichotic listening tasks as compared to the difficulty of monaural listening tasks. Fifty percent-correct thresholds between the right and left ear were not significantly different, although the right ear displayed a steeper slope than the left ear. These results were consistent with the presence of a dichotic right-ear advantage.

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## Chapter 1

### **INTRODUCTION AND LITERATURE REVIEW**

#### Dichotic Listening

In dichotic listening, a subject listens to two competing messages presented simultaneously with one message in each ear. The subject is then asked to recall the messages either in a specific order or in any order they choose (Bryden, 1988). The messages presented in the two ears will never be the same, although they may differ by varying degrees. The original purpose of this procedure was to simulate the situation of air traffic controllers who often receive flight information from more than one airplane at a time in separate ears (Broadbent, 1954). Now dichotic listening tasks are used clinically to test the strength of the neural auditory system in both children and adults. The results of dichotic listening tasks can be used to diagnose a variety of pathologies including brainstem and cortical disorders as well as auditory processing disorders (Martin & Clark, 2009).

Dichotic listening tasks can be completed in either a free-recall response format or a directed-attention format. In the free-recall response format, the subject is asked to recall both the words they hear in any order they wish (Roup et al., 2006). Usually, given multiple pairs of stimuli, the subject will first recall all the stimuli presented to one ear followed by all the stimuli presented to the other (Broadbent, 1954). One problem with this method is that whichever items the subject chooses to report second must be held in the short-term memory for a longer period of time. This decreases the likelihood that those items will be recalled correctly, which can skew the results of the test, especially when determining ear advantages (as discussed later). One solution to this issue is to use the directed-attention format instead (Bryden, 1988). In the directed-attention response format, the subject is cued to one ear or the other before the stimulus

is presented. The subject may be asked to recall just the stimulus word from one ear while ignoring the stimulus word presented to the other ear, or he or she may be asked to recall the stimuli in a specific order. The latter method is typically the most difficult for most listeners (Roup et al., 2006).

Dichotic listening tasks in general tend to be more difficult than monaural listening tasks. It is expected that subjects will perform significantly worse on a dichotic listening task than a comparable monaural listening task. Even though a subject is able to easily recognize a list of words when it is presented one word at a time to just one ear, much difficulty can be encountered when the same words are dichotically paired and presented to both ears at the same time (Roup et al., 2006).

Verbal stimuli options for dichotic listening tasks include consonant-vowel syllables, words, sentences, and digits. The different types of stimuli offer various levels of difficulty when used in dichotic listening tasks. In a study by Noffsinger, Martinez, and Wilson (1994), digits were found to be the easiest stimulus to correctly recall in a dichotic listening task, followed closely by sentences. Both of these types of stimuli were correctly recalled over 90% of the time for both ears in a group of normal hearing young adults. Nonsense consonant-vowel syllables proved to be significantly more difficult with accuracy levels at just over 70% for both ears (Noffsinger et al., 1994). Occasionally, nonverbal stimuli is used for dichotic listening tasks, such as the use of dichotic musical chords in tests for central auditory processing disorders (Musiek & Chermak, 1994).

Most often, digits are used as stimuli for dichotic listening tasks because they limit the number of contextual cues that words and sentences provide, are easily recognizable by listeners with a hearing loss, provide a limited set of possible responses, and limit the effects of the right-

ear advantage (Noffsinger et al., 1994; Speaks et al., 1985; Musiek & Chermak, 1994). Words, however, may have several advantages over digits because they are a much less restricted set than digits which allows for word sets of varying difficulties. There are also currently many standardized, recorded lists of words available which allows for performance comparisons across patients or subjects. The greatest benefit, however, may lie in using a combination of all stimulus options in dichotic listening tasks to obtain an even wider range of difficulties than just words alone allow for (Noffsinger et al., 1994; Roup et al., 2006).

### The Right-Ear Advantage

In verbal dichotic listening tasks there tends to be a right-ear advantage, or a trend towards more accurate reporting from information that is received by the right ear. There are two major explanations for this occurrence and it is not unlikely that both models are at least partly correct and play a role in explaining the right-ear advantage (Bryden, 1988). One theory is that by anticipating verbal input, we activate the language areas of the brain in the left hemisphere, thus making it more sensitive to incoming information received by the right ear (Kinsbourne, 1970). Another explanation is that this effect results because most of the information received by the right ear is sent to the left hemisphere of the brain where the language processing centers of the brain lie (Kimura, 1967; Strouse & Wilson, 1999).

Each ear has two neural pathways to the brain. The first and more efficient is the contralateral pathway. This pathway leads from the ear to the opposite side of the brain. That is, the left ear contralateral pathway goes to the right temporal lobe and the right ear contralateral pathway leads to the left temporal lobe. The second neural pathway from the ear to the brain is the ipsilateral pathway. This pathway is less efficient than the contralateral pathway and goes

from the ear to the same side of the brain. This means that the ipsilateral pathway of the right ear goes to the right temporal lobe and the ipsilateral pathway of the left ear leads to the left temporal lobe (Bryden, 1988; Kimura, 1961).

Kimura (1961) studied the effects of temporal lobe damage on auditory perception. Her research offers explanations on how the brain processes auditory verbal material and why the right-ear advantage occurs. While subjects with left temporal lobe damage had little trouble recognizing digits presented to just one ear, they had more trouble with dichotic digit tasks than subjects with right temporal lobe damage. This suggests that the left temporal lobe is vital to recognizing verbal material presented auditorily and even more so when both ears are involved in the task. Another effect observed was that in subjects with temporal damage on either side, there was trouble recognizing digits arriving to the ear contralateral to the damaged lobe. Once again, this effect only occurred in dichotic listening tasks. This suggests that both temporal lobes play a role in auditory comprehension of verbal material and that the contralateral pathway to a lobe is more effective than the ipsilateral pathway to the same lobe (Kimura, 1961).

Because both of these observations only occurred in dichotic listening situations, it indicates that there must be competition between the contralateral and ipsilateral pathways traveling to one lobe in which the contralateral pathway is stronger. If one lobe is damaged, it means that one of the ears is relying on only its ipsilateral pathway to the brain. This pathway may be sufficient for material that is familiar or simple, but when the other ear is also receiving information, such as in a dichotic listening task, the ipsilateral pathway must compete with the contralateral pathway from the other ear. In this situation, the contralateral pathway prevails, causing problems in recognizing the speech signal, especially from the ear contralateral to the damaged lobe (Kimura, 1961). A right-ear advantage in dichotic listening occurs then because

the contralateral pathway from the right ear to the left temporal lobe is more efficient than the ipsilateral pathway leading to the right temporal lobe. This means that more information goes to the left temporal lobe: the most important part of the brain for processing verbal material. In addition, most auditory information received by the left ear must first travel to the right temporal lobe and then to the left temporal lobe via the corpus callosum. Information is lost in this transfer, giving the left ear a disadvantage (Kimura, 1961; Bryden, 1988).

Several studies (Wilson & Leigh, 1996; Strouse & Wilson, 1999; Dobie & Simmons, 1971) have been done to compare left-handed subjects with right-handed subjects to determine if the right-ear advantage is an effect displayed only by right-handed people and thus left-handed people will display a left-ear advantage. This would occur because it is believed that most right-handed people are left-brain dominant and thus right-ear dominant, whereas most left-handed people are right-brain dominant and thus left-ear dominant. Wilson and Leigh (1996) tested 24 right-handed subjects and 24 left-handed subjects in order to analyze this possible effect. They found that while both groups did demonstrate a right-ear advantage, the advantage was greater for subjects who were right-handed. They also observed that while the majority of participants in each group showed a right-ear advantage, there were more subjects who showed a left-ear advantage in the left-handed group than in the right-handed group. It follows that there were more participants with a right-ear advantage in the right-handed group than in the left-handed group. Overall, there was more variability in performance from the left-handed group than the right-handed group, but no evidence for a strong left-ear advantage effect in left-handed people. (Wilson & Leigh, 1996).

These trends for handedness and right- or left-ear advantages were confirmed in a study by Strouse and Wilson (1999). In this study involving an uncertainty variable (subjects did not



know how many pairs of digits they would have to recall in a given trial), left-handed subjects showed more variability in their responses than right-handed subjects, just as in Wilson and Leigh's (1996) study. In addition, in a study of dichotic listening in which the intensity level between the signal in the right and left ear differed, left-handed individuals did show a slight advantage for the left ear. In the same task, however, right-handed individuals displayed a right-ear advantage that was more significant (Dobie & Simmons, 1971).

There are some cases, however, in which a relatively strong left-ear advantage can be observed. When Roup, Wiley, and Wilson (2006) tested various ages of subjects in a directed-attention left dichotic listening task (subjects were asked to recall the word presented to the left ear followed by the word presented to the right ear), both younger and older adults showed a left-ear advantage. The left-ear advantage was, however, smaller and more variable than the right-ear advantage observed on an identical task involving the right ear (Roup et al., 2006).

Another interesting study involving ear-advantages performed by Ling (1971) tested normal and hearing-impaired children using dichotic listening tasks. The hearing-impaired subjects showed no predominant right-ear advantage; rather these children displayed a random assortment of both right- and left-ear advantages. These advantages did not correlate with a better hearing ear as determined by both pure tone tests and monaural word scores, and were actually more defined than the advantages shown by the normal-hearing children. The hearing-impaired children often claimed that they either only heard one signal as if it was presented in both ears or that the signals were distorted. This suggests that in hearing-impaired children, a masking or distortion effect is created and that rather than integrating the two signals as in normal hearing individuals, one is suppressed (Ling, 1971).

Left-ear advantages can often be observed when a nonverbal stimulus, such as music or an environmental sound, is presented to a subject in a dichotic listening task. This occurs because the left ear sends most of its incoming auditory information to the right temporal lobe, where nonverbal information of this type is most efficiently processed (Bryden, 1988). In Kimura's (1961) study, it was found that patients with left temporal lobe damage had little trouble identifying nonverbal sounds that patients with right temporal lobe damage did have problems with. The left-ear advantage can thus be explained very similarly to the right-ear advantage; because of differences in hemispheric specialization and the strength of the contralateral and ipsilateral pathways. Left-ear advantages as calculated in nonverbal dichotic listening tasks may even be understated due to the verbal component of the task whereby the subject must say what they have heard (Bryden, 1988).

Another trend in right-ear advantages is that as the stimulus materials become more difficult, responses will become less accurate. Wilson and Jaffe (1996) found that as subjects moved from recalling just one pair of digits at a time to recalling four pairs of digits at a time, accuracy decreased significantly. Due to the right-ear advantage, accuracy decreased much faster as difficulty increased for stimuli presented in the left ear than it did for the right ear (Wilson & Jaffe, 1996). A similar effect can be observed in dichotic tasks where participants do not know how many stimuli will be presented to them. Strouse and Wilson (1999) also tested subjects on recalling sets of one pair to four pairs of digits presented dichotically, except in this study the subjects had no prior knowledge of how many pairs would be presented in each trial. This added variable was found to further enhance the right-ear advantage when compared to the data from Wilson and Jaffe's (1996) research.

The right-ear advantage is an effect observed in various types of dichotic listening tasks and is found most consistently in right-handed individuals. A left-ear advantage can sometimes be displayed more frequently by left-handed subjects or in dichotic tasks involving nonverbal stimuli. Both of these effects can be at least partly attributed to the nature of the pathways leading from the ear to the brain.

### The Effects of Age and Gender on Dichotic Listening Task Performance

In general, young adults perform better on all types of dichotic listening tasks than older adults because they have more efficient neural pathways and more sensitive hearing. Also, the corpus callosum, or bundle nerves connecting the two hemispheres of the brain tends to be more efficient in younger adults due to demyelination that occurs with age (Bellis & Wilber, 2001). Performance from older adults also tends to be more variable. The greatest difference between the age groups is in left-ear performance compared to right-ear performance due to the right-ear advantage (Strouse & Wilson, 1999; Wilson & Jaffe, 1996).

In a study by Roup, Wiley, and Wilson (2006), right-ear advantages were observed in all age groups using a free-recall response format, however, older adults showed a more exaggerated advantage than younger adults. This exaggeration is in part due to a left-ear disadvantage, where poor recognition of stimuli presented to the left ear makes the performance of the right ear appear much better in comparison. Right-ear advantages were also observed in directed-attention right tasks, where subjects were asked to repeat the word presented in the right ear followed by the word presented in the left ear. In this response condition, the right-ear advantage for older adults was even more pronounced than in the free-recall response condition (Roup et al., 2006).

The type of stimulus used in a dichotic listening task can also have an effect on how older adults' performance compares to the performance of younger adults. Noffsinger, Martinez, and Andrews (1996) tested 19 adults between the ages of 58 and 85 years using digits, sentences, and nonsense monosyllabic syllables as stimuli for dichotic listening tasks. All types of stimuli revealed a right ear advantage. When compared to younger adults, the results from the digit stimuli were very similar with the older adults performing just slightly poorer. Older adult performance on the sentence task, however, was much poorer than that of the young adults in the same task. In addition, older adult performance on the nonsense syllable task was even worse than that of the sentence task (Noffsinger et al., 2006).

Bellis and Wilber (2004) also looked at the effects of age on dichotic listening tasks and the right-ear advantage, but with an added variable: gender. This study broke subjects into four age groups and supported earlier findings regarding age effects. The older subject groups (specifically those subjects over age 55) performed worse on the dichotic listening tasks than the younger groups and exhibited the poorest performance with the left ear. Only one group of the five exhibited a significant difference in performance between the genders. In this group, which contained subjects aged 35 to 40 years, the men displayed a significantly larger right-ear advantage than the women. Overall, the increase in right-ear advantage associated with age occurred earlier for men than it did for women. This suggests and is supported by other research claiming that women experience degradation of the corpus callosum later in life than men do (Bellis & Wilber, 2001).

There does not, however, seem to be a strong link between gender and the number of people who show a right-ear advantage on dichotic listening tasks, although some weak trends do arise. Men tend to be somewhat more lateralized than women, which means that men show a

right-ear advantage more often than women do. Bryden (1988) analyzed the results of a dichotic listening tasks from a group of men and women and found that while 74% of the males displayed a right-ear advantage, only 50% of the women showed a right-ear advantage. While some similar studies show less of a gap between the genders, there is currently no evidence suggesting that women are more lateralized than men (Bryden, 1988).

In general, men may be somewhat more likely to exhibit a right-ear advantage, and this advantage may increase with age earlier than it does in women. Older adults exhibit larger right-ear advantages and have more difficulty with dichotic listening tasks of various types. These observations mean that slightly different results can be expected on dichotic listening tasks depending on both the age and gender of the individual.

#### Psychometric Functions for Monaural Listening Tasks

For any test that requires a behavioral response from a listener, it is important to understand the relationship between the stimulus and the responses given. One way of characterizing this relationship is by generating a psychometric function, or in the case of speech recognition, a performance-intensity function. These functions display percentage of correct responses as a function of intensity in dB HL. Information obtained from the performance-intensity function may be used clinically to determine the site of lesion, the magnitude of the communication handicap, the accuracy of pure-tone thresholds, reverberation information and various information regarding amplification and hearing aids such as amplitude compression (Beattie & Warren, 1983, Boothroyd, 2008).

Beattie and Raffin (1985) tested 20 normal hearing young adults using the CID W-22, a set of monosyllabic words, presented monaurally to develop a performance-intensity function of

word recognition. They found thresholds (defined by the point at which 50% of responses are correct) to be around 28.3 dB HL. The slope of their function (found by averaging the score at each intensity) was found to be 4.54%/dB (Beattie & Raffin, 1985). Wilson, et al. (1990) developed a performance-intensity function using the NU-6 word list and found similar results. Slope was 4.5%/dB with a 50%-correct threshold between 16 and 20 dB HL (Wilson, et al., 1990). These findings are in agreement with the generally accepted standards for monaural listening tasks, which is a slope of 4.5%/dB over the 20-80% intelligibility range with a maximum at around 25 dB SL (Beattie & Warren, 1983).

In a study by Beattie and Warren (1983), it was determined that even in subjects with mild to moderate sensorineural hearing loss, there is no significant effect on the slope of the performance-intensity function due to the degree of the hearing loss. Over a range of hearing loss from 15 to 60 dB HL, the average slope was found to be 3%/dB; not a statistically significant difference from the slope of a normal hearer's performance-intensity function (Beattie & Warren, 1983). This is consistent with results found by Beattie and Raffin (1985) where the slope of the performance-intensity function for subjects with a mild to moderate sensorineural hearing loss was found to be 3%/dB. There does seem to be, however, a weak relationship between audiometric configuration of a hearing loss and slope of the performance intensity function. From flat to precipitously sloping audiograms, slope decreased from an average of 3.3%/dB to 1.8%/dB, a statistically significant difference. Differences in the trends of performance-intensity functions of normal hearing individuals versus those with a hearing loss, such as those stated, can have clinical applications in how a patient is tested in order to produce the most accurate and informative performance-intensity function for that individual (Beattie & Warren, 1983).

There are several methods by which the average slope of performance-intensity function can be obtained for a group of people. Traditionally slope has been found by averaging the performance percentages of all subjects at each fixed intensity level and then finding the slope of the resulting function. However, a more accurate method of measuring slope may be to first calculate the slope of each individual participant's function by fitting a quadratic polynomial equation and then finding the average of the slopes. These two methods produce significantly different slopes, with the first producing a slope that is often skewed if the individual functions are widely dispersed along the x-axis (Beattie & Warren, 1983).

Another important factor to take into consideration when finding the slope of a performance-intensity function is over which interval the slope will be measured. Typically, slope is found over the 20-80% intelligibility range. However, taking the slope of this section of a function may not accurately represent the data, as one portion of the function may have a slope that is significantly different from the slope of another portion of the function. This is an especially crucial factor to take note of when comparing data from different studies (Beattie & Warren, 1983).

### Psychometric Functions for Dichotic Listening Tasks

Several studies have created psychometric functions for dichotic listening tasks, or tasks involving both ears rather than just one. Beattie (1989) studied the effects of word recognition in multi-talker noise for normal and hearing impaired listeners. The first part of this study involved varying the signal-to-noise ratio from 0 to 24 dB by keeping words from the CID W-22 list at a constant 45 or 65 dB HL and varying the level of the noise. The slope of the average performance-intensity function was found to be 5.15%/dB for normal hearing listeners and a

more gradual 2.6%/dB for hearing impaired listeners. The second part of the study involved varying the signal-to-noise ratio by varying the intensity of the word list from 0 to 48 dB SL and keeping the level of the noise constant. This produced a performance-intensity function with a slope of 4.32%/dB for normal hearing listeners and a function with a slope of .97%/dB for hearing impaired subjects (Beattie, 1989).

Dobie and Simmons (1971) created a psychometric function based on the results of a dichotic listening task and varied differences between the intensities of the simultaneously presented stimuli. Nonsense syllables were used with right- and left-handed, as well as normal and brain-damaged subjects. The performance-intensity function represented percentage of correct responses as a function of the difference in intensity between the signal presented in the right ear and the signal presented in the left ear. Slopes were not calculated in this study and the shapes of the graphs varied greatly depending on handedness and brain function (Dobie & Simmons, 1971).

The Beattie (1989) study looked at the resultant performance-intensity functions of putting competing signals in the two different ears, but used noise as one signal and words as the other. The Dobie and Simmons (1971) study created a performance-intensity function based on differences in intensity levels between stimulus items, but did not study the results when intensity levels are kept constant. The current study intends to create a performance-intensity function based on the dichotic listening results from normal hearing young adults in a task involving the use of words as both signals and with equal intensity levels between stimuli within each pair.

In general, this study hopes to further define the performance characteristics of dichotic listening tasks. Rather than developing a performance-intensity function that shows the results of



word recognition for stimuli presented in one ear, which has been repeatedly tested and supported, this study will develop a function showing word recognition as presented in a dichotic listening task. Development of a performance-intensity function for dichotic listening could be a useful in a clinical setting in helping to interpret a patient's dichotic listening results. The study will attempt to answer several questions regarding dichotic listening and the corresponding performance-intensity function. These questions are as follows:

1. Does the shape and/or slope of the performance-intensity function for dichotic listening differ from that of monaural listening?
2. Does the shape and/or slope of the performance-intensity function for dichotic listening differ between the right and left ear?

## **Chapter 2**

### **METHODS**

#### **Subjects**

Ten subjects from The Ohio State University ranging in age from 19-21 years participated in this study. Three subjects were male and 7 subjects were female. All subjects were right handed as determined by the Edinburgh Handedness Inventory (Oldfield, 1971; see Appendix A). This task requires subjects to determine his or her hand preference in various tasks. Any subject scoring  $\leq 20$  on the inventory was eligible for participation. Subjects were also native speakers of English with no major current or past ear-related illnesses. In addition, all participants demonstrated pure tone thresholds of  $\leq 20$  dB HL over the 250-8000 Hz frequency range with no air bone gaps exceeding 10 dB over the 500-4000 Hz range. Subjects had normal otoscopy results (unobstructed ear canal, normal tympanic membrane, no structural abnormalities) and had tympanograms within the normal limits. Subjects were compensated for their participation in this study.

#### **Stimuli**

The present study used the Northwestern University Auditory Test Number 6 (NU-6) monosyllabic words from the Department of Veterans Affairs compact disc (Speech Recognition and Identification Materials 1.1, Department of Veterans Affairs, 1991). These 200 words were used to create 100 dichotic pairs in a procedure described by Roup et al (2006). Each dichotic pair was spoken by a female speaker and included the carrier phrase “say the word.” The words were randomly arranged into lists of 25 pairs each (Roup et al, 2006).

## Procedure

Each subject was first tested using otoscopy, tympanometry, and pure-tone audiometry to determine eligibility for participation in the study. Those who met the criteria were then presented with the dichotic stimuli. Each subject was presented with a total of 12 lists consisting of 25 dichotically paired NU-6 words each. Each list was presented at one of six intensity levels and each intensity level was presented twice. The intensity levels were in 8 dB steps from 8-48 dB HL. Half of the subjects began at the lowest intensity level, ascended to highest, and then descended back to the lowest. The other half of the subjects began at the highest intensity level, descended to the lowest, and then ascended back up to the highest. Subjects were asked to verbally recall both of the words that they heard in each pair in a free-recall response format. Each incorrect response was noted, although no feedback was given to the participant. Before the task, subjects were familiarized with the procedure by performing one of four practice lists that were not scored.

Two pilot subjects were tested to more clearly define an appropriate intensity level step size and maximum and minimum intensity levels. The pilot subjects were tested at the intensity levels of 0, 10, 20, 30, 40, and 50 dB HL. The results from the pilot subjects indicated that performance at 0 and 10 dB HL was very similar because both intensity levels were so low, resulting in poor performance with close to 0%-correct recognition. Similarly, in the higher intensity levels there was little difference in performance indicating that subjects were reaching their maximum performance before 50 dB HL. In order to limit redundancies in testing, the minimum intensity level was changed to 8 dB HL and the maximum was changed to 48 dB HL. A step size of 8 dB HL was used so that six intensity levels could still be tested, but more

information could be obtained from the middle range of intensities, rather than redundant information about minimum and maximum performance.

Testing took place in a sound-proof booth. The stimuli was routed from a CD player (Sony CE375) to the audiometer (Grason Stadler, Model 61) and presented to the subject via insert headphones (Etymotic ER-3A). All audiologic equipment (audiometer, tympanometer) was calibrated according to the standards set by the American National Standards Institute (ANSI, 2004).

### **Chapter 3**

#### **RESULTS**

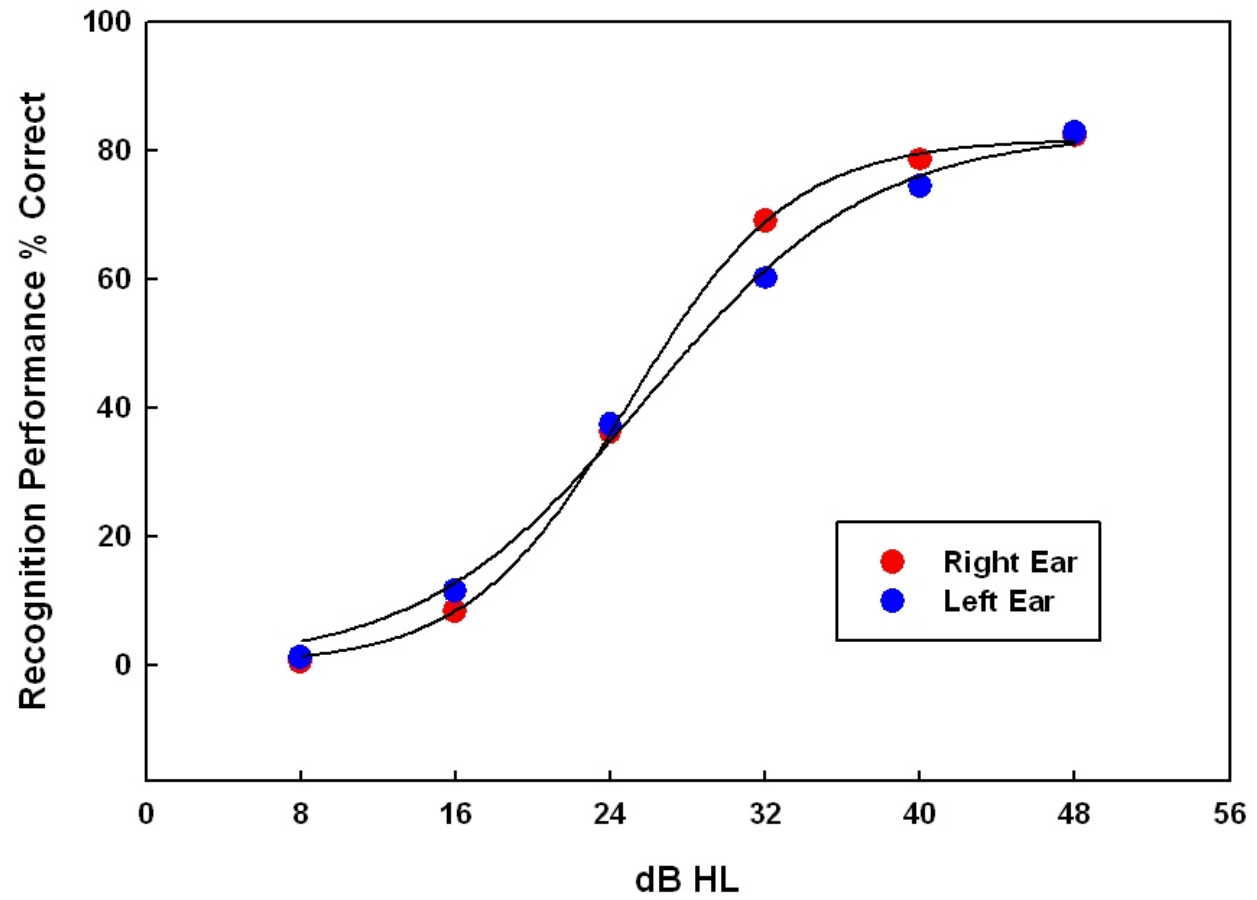
Mean dichotic word recognition scores (in percent correct) and standard deviations are presented in Table 1. Data is shown for each intensity level for the right ear, left ear, and ear advantage (RE-LE) in percentage correct. As shown in Table 1, as intensity level increased so did the percentage of correct responses in both ears. Table 1 also indicates that performance was better in the left ear for the intensity levels of 8 dB HL, 16 dB HL, 24 dB HL, and 48 dB HL, resulting in a left-ear advantage at all of these intensity levels. Performance was better in the right ear for the intensity levels of 32 dB HL and 40 dB HL, resulting in a right-ear advantage at these intensity levels.

Figure 1 shows the resultant average performance-intensity function for the right and left ears. The mean dichotic word recognition scores were plotted on the ordinate with intensity level on the abscissa. The 50%-correct threshold of the function for the right ear occurred at 28.76 dB HL. Similarly, the 50%-correct threshold of the function for the left ear occurred at 29.66 dB HL.

The slope of the performance-intensity function was found by calculating a best-fit linear regression of the data points at 16, 24, 32, and 40 dB HL. This was calculated excluding the lowest and highest intensity levels so that the regression better modeled the data. The slope of the performance-intensity function was 3.05 %/dB for the right ear and 2.64 %/dB for the left ear. The slope of the performance-intensity function for the right ear was steeper than that of the left ear, indicating that subjects reached their maximum performance sooner with words presented in the right ear than they did with words presented in the left ear.

<b>Intensity Level</b>	<b>Right Ear (%)</b>	<b>Left Ear (%)</b>	<b>RE-LE (%)</b>
<b>8 dB HL</b>			
Mean	0.6	1.2	-0.6
SD	1.35	1.69	2.12
<b>16 dB HL</b>			
Mean	8.4	11.6	-3.2
SD	5.95	7.59	7.38
<b>24 dB HL</b>			
Mean	33.2	37.4	-4.2
SD	9.30	15.75	13.51
<b>32 dB HL</b>			
Mean	69.0	60.2	8.8
SD	9.06	11.25	11.20
<b>40 dB HL</b>			
Mean	78.6	74.4	4.2
SD	7.55	9.70	10.22
<b>48 dB HL</b>			
Mean	82.2	82.8	-0.6
SD	8.51	9.58	8.06

**Table 1.** Means and standard deviations (in percent) for the right and left ear dichotic word recognition performance across the six different intensity levels.

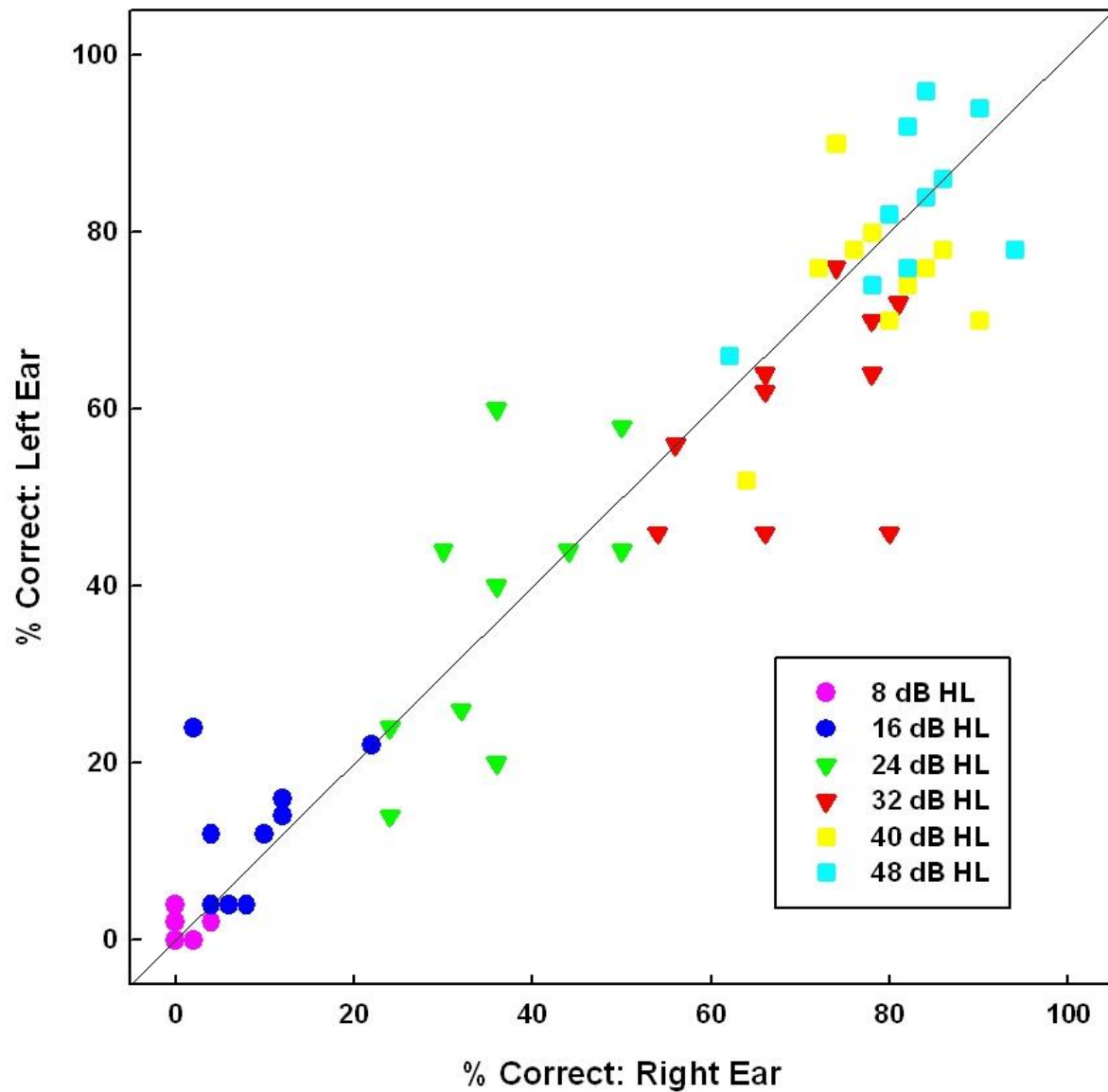


**Figure 1.** Average performance-intensity function for the right and left ears.

Figure 2 shows individual recognition performance data as a scatter plot. Percent correct for words presented in the right ear is represented on the abscissa and percent correct for words presented in the left ear on the ordinate. The diagonal line through the plot represents equal performance in both ears. Points falling below the line represent instances where performance was better in the right ear than in the left ear. Points above the line indicate better performance in the left ear when compared to the right ear. As shown in Figure 2, points are clustered more closely together in the lowest and highest intensity levels tested, indicating more consistent performance across subjects at these intensity levels. At 8 dB HL, the lowest intensity level tested, subjects were consistently scoring very poorly. Similarly, at 40 and 48 dB HL, the two highest intensity levels tested, subjects were at or near their maximum performance level and thus consistently scoring very well. The points representing 16, 24, and 32 dB HL had a greater spread, indicating more variability in performance across subjects at these intensity levels.

A paired *t*-test of means was used to determine if the 50%-correct threshold differed between right and left ears. Results revealed that the difference in the 50%-correct thresholds of the two functions was not statistically significant ( $t_{18} = -.06$ ;  $p > .05$ ). A paired-sample *t*-test of means was also used to determine if the slope of the performance-intensity function differed between right and left ears. Here, the difference in slopes between the two functions was found to be statistically significant ( $t_{18} = 2.3$ ;  $p < .05$ ). Even though subjects reached their 50% correct threshold at or near the same intensity level for both ears, they tended to reach their maximum performance level more quickly with the words presented to the right ear than with the words presented to the left ear.





**Figure 2.** Individual recognition performance data as a scatter plot. Points falling below the line represent instances where performance was better in the right ear. Points above the line indicate better performance in the left ear.

## **Chapter 4**

### **DISCUSSION**

The purpose of this study was to create a performance-intensity function representing dichotic word recognition performance in the right and left ears, and to compare that function to performance-intensity functions of monaural listening tasks. This study also intended to look at the differences in performance between the two ears and possible ear advantage effects.

The s-shaped performance intensity function (see Figure 1) obtained from this study is characteristic of monaural performance intensity functions, such as those found by previous monaural studies (Beattie & Raffin, 1985; Beattie & Warren, 1983; Wilson et al., 1990). The Wilson et al. (1990) study used the same NU-6 words that were used in the present study in a monaural listening task designed to produce a performance-intensity function. Fifty percent-correct thresholds obtained from the present study at 28.76 dB HL for the right ear and 29.55 dB HL for the left ear were substantially higher than results from Wilson et al. (1990), which found 50%-correct thresholds to be between 16 and 20 dB HL. In the same study by Wilson et al. (1990) subjects performed at around 85% correct at 28 dB HL. Compared to the present study, where subjects were performing at about 85% correct at 48 dB HL, similar levels of performance were obtained at much lower intensity levels by Wilson et al. (1990). Together, these results suggest that it takes a more intense signal in a dichotic listening task than in a monaural listening task for subjects to reach the same level of recognition performance. The higher intensity values for equal performance in the dichotic test are most likely a reflection of the increased difficulty of the test as compared to a monaural test.

The slopes of the performance-intensity functions from the present study also differed from the results of Wilson et al. (1990). Wilson et al. (1990) found slopes for their monaural

tasks using the NU-6 word lists of 4.5 %/dB, whereas the present study found slopes of 3.05%/dB for the right ear and 2.64%/dB for the left ear (Wilson, et al., 1990). The slope for monaural listening tasks tends to be steeper than was found in this study's dichotic listening task. This means that in monaural listening tasks, subjects reach their maximum performance more quickly than they do in dichotic listening tasks. Just as for the 50%-correct threshold, this difference in slope may be because monaural listening tasks tend to be easier than dichotic listening tasks. If subjects are performing well at lower intensity levels on an easier listening test such as a monaural task, it makes sense that they would reach the maximum performance before they would reach it on a more difficult listening test such as a dichotic task.

The present study also compared performance-intensity functions for the right and left ears. While 50%-correct thresholds for performance in the right and left ear were similar at 28.76 and 29.55 dB HL, respectively, the slopes were significantly different between the two ears. The slope of the performance-intensity function for the right ear, at 3.05 %/dB, was significantly steeper than the slope of the performance-intensity function for the left ear at 2.64 %/dB. This indicates that subjects reached maximum performance in the right ear sooner than in the left ear, which may be consistent with the right-ear advantage found in previous studies (Wilson & Leigh, 1996; Strouse & Wilson, 1999). Because the right ear is more efficient than the left ear at processing dichotic stimuli due to the nature of the auditory neural pathways, it is not surprising that performance on words presented to the right ear would reach maximum sooner than would the left ear (Kimura, 1967). Said another way, if performance on words presented to the right ear is consistently better than performance on words presented to the left ear, it makes sense that the right ear would reach maximum performance before the left ear would.

Interestingly, while the slopes of the performance-intensity functions for the right and left ear support the existence of a right-ear advantage, it is not always so for the individual intensity levels. The only intensity levels at which a right-ear advantage occurred were at 32 and 40 dB HL, although at 8 and 48 dB HL, the left-ear advantages were extremely small. The right ear gained its advantage at some point in between 24 dB HL and 32 dB HL. The 50%-correct thresholds (28.76 dB HL and 29.55 dB HL) also occur in this range. In general terms, the left ear seemed to have the advantage before reaching the 50%-correct threshold, at which point the advantage switched to the right ear. This may suggest that the right-ear advantage has a greater effect on performance at some intensity levels than at others, specifically at intensities where a subject is already performing above his or her 50%-correct threshold. Further research would be needed to verify and explain this result.

#### Clinical Implications and Future Research

Dichotic listening tasks are often used clinically to diagnose auditory processing disorders and other brainstem and cortical pathologies (Martin & Clark, 2009). A performance-intensity function of average or expected performance allows for comparisons to be made, which is useful when determining if a patient's performance is atypical and therefore some sort of auditory deficit may be present.

This study developed a dichotic listening task performance-intensity function based on the performance of only 10 subjects. In order to create a performance-intensity function that could be used clinically and to which other normal hearing young adults could be compared, further testing with more subjects would be needed. Other types of stimuli such as digits or syllables could be tested, as well. This would allow for different difficulties of dichotic tasks to

be performed and then compared to an average performance-intensity function. Future research might also include the development of dichotic performance-intensity functions for those with different types of hearing loss. This type of study would yield typical performance-intensity functions of certain pathologies, which would be useful clinically when making a diagnosis.

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## Appendix A

### Handedness Inventory

*Please indicate your preferences in the use of hands in the following activities by checking the appropriate column.*

*Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.*

*Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.*

	LEFT	RIGHT
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking Match (match)		
10. Opening Box (lid)		